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SwissFEL X-band RF front end

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Abstract

For the upcoming X-band (11.9952 GHz) systems at SwissFEL a RF front end based on direct up conversion and single stage superheterodyne down conversion is currently in development. The required jitter stability of the overall RF station is 0.0072 deg (rms) and 1.8e-4 amplitude relative (rms).

This poster presents the overall concept and challenging components. They include the vector modulator, LO generation and image rejection mixers, required to overcome difficulties in direct up conversion and low IF down conversion. Preliminary lab test results of some individual prototype components are presented.

Overview

Based on a prototype tested during November 2018 shutdown, this poster presents the concept and development status of a direct conversion X-band front end required for the upcoming two X-band systems at SwissFEL. While the 16-channel receiver is based on single stage IF down conversion (Superhet), the transmitter applies direct IQ up conversion and fast PIN switching in case of an interlock. Unlike previous X-band RF front ends, this front end requires only a single subharmonic S-band (2.9988 GHz) reference input, thus avoiding the need of an external frequency multiplier box.

However the design of a multi-channel X-band direct conversion front end yields to some general and more specific challenges like:

- Crosstalk between receiver channels (> 70 dB required)
- LO signal distribution with high output isolation
- Low IF single stage down conversion requires a very narrow (0.33 %) shifted LO frequency to be generated with very low noise and spurious content
- Low IF single stage down conversion also introduces image noise (especially from broadband sources) which cannot be filtered out due to impractical high Q requirements for an appropriate image filter
- Direct up conversion with low PM ↔ AM conversion requires a precisely balanced IQ mixer architecture with active offset compensation
- Phase and amplitude drifts caused by humidity and temperature changes.

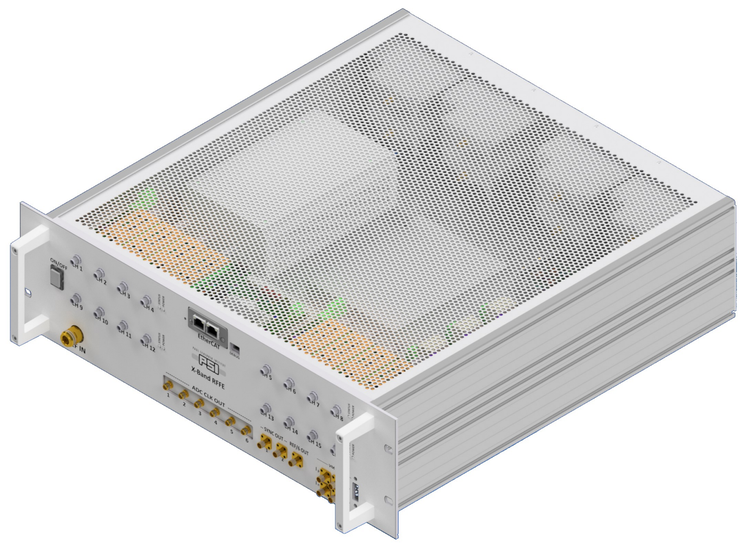

Figure 1: 3U X-band RFFE (isometric view)

Front end concept

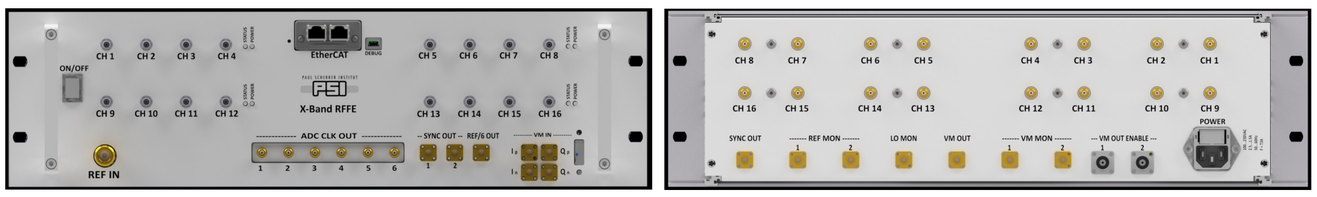

Figure 2: 3U X-band RFFE (front & back view)

Down converter channels (CH#)	16x (12 GHz → 40 MHz) SMA
Up converter channels (VM OUT)	1x (13 dBm @ Full Scale) SMA
Reference input (REF IN)	1x (3 GHz) N
ADC/DAC clock (ADC CLK OUT)	6x 250 MHz SMA
General purpose clocks (SYNC OUT; REF IN/6)	3x 40 MHz; 1x 500 MHz SMA
RF Reference monitoring (REF_{mon})	1x S-band; 1x X-band SMA
RF signal monitoring (LO MON; VM MON1/2)	1x LO; 2x Vector Modulator SMA
TX differential input (VM IN)	4x SMA; 1x S-ATA
TX enable input (VM OUT ENABLE)	2x logical AND connected (TTL) BNC
EPICS Integration (IF Gain, Temp., Humidity, LO, Voltage/Current)	1x Anybus EtherCAT interface

Table 1: X-band RFFE connection summary

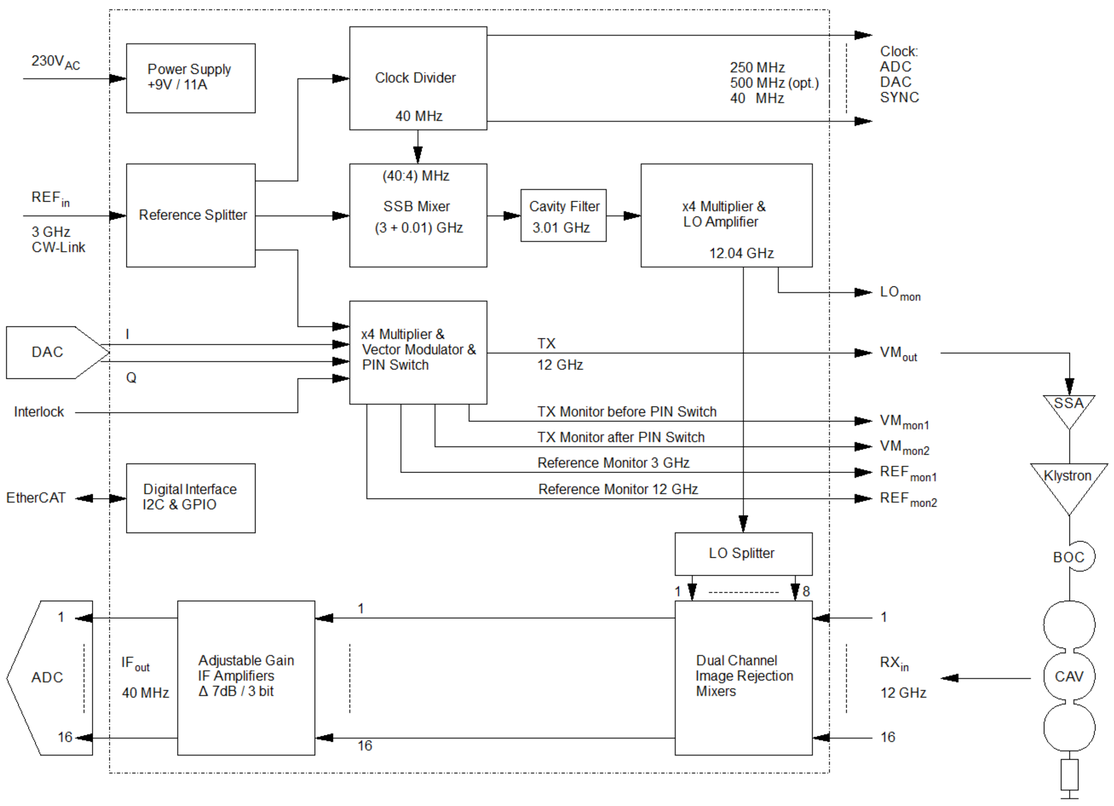

Figure 3: X-Band RFFE block diagram

RF components

Dual channel image rejection mixer

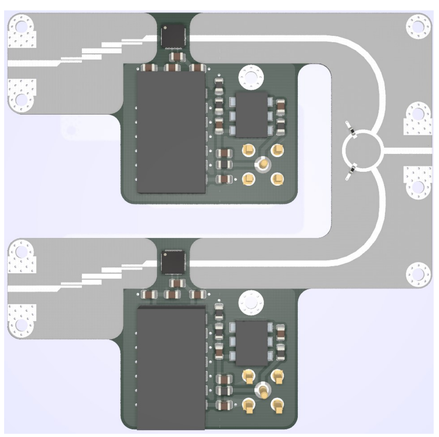

Figure 4: Dual channel IRM PCB

- 7 dB conversion loss @ 18 dBm LO drive
- 3rd order coupled line band-pass filter
- Typically 30 dB image rejection @ 40 MHz IF
- Broadband IF quadrature coupler 10-80 MHz
- Utilizes 2nd order hybrid-lattice filter to optimize phase linearity

Vector modulator with x4 LO multiplier / PIN switch

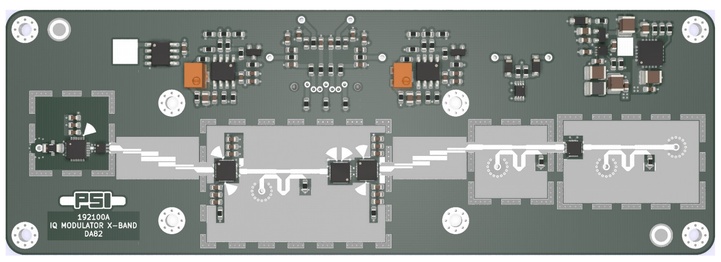

Figure 5: Vector Modulator with x4 multiplier / PIN switch PCB

- x4 multiplier buffered LO input with low additive phase noise of -135 dBc/Hz @ 10 kHz offset
- Differential or single-ended baseband input with on board active IQ offset correction
- 10 ns PIN diode switching speed (RF on to RF off) with typically 48 dB RF off attenuation
- On board directional couplers for signal monitoring
- Low phase noise (-165 dBc/Hz @ 10 kHz offset) custom MMIC LO & RF buffer amplifiers
- Measured < 0.2 dB of PM to AM conversion

Single sideband mixer with active carrier suppression

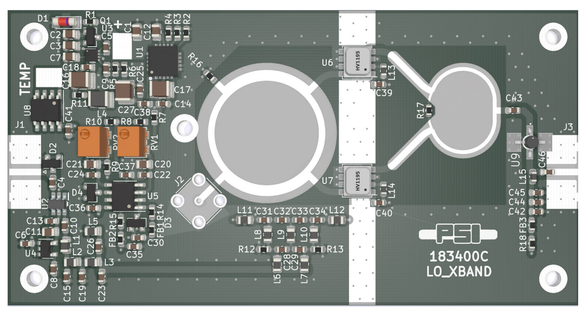

Figure 6: SSB Mixer with active carrier suppression PCB

- IF input divider (40 MHz → 10 MHz)
- Discrete single sideband mixer for low noise subharmonic LO generation of 3.01 GHz
- x4 multiplier located before LO amplifier generates required LO of 12.04 GHz
- Active IQ offset correction to adjust carrier leakage > 60 dBc

KiCad

Absolute phase noise at IF

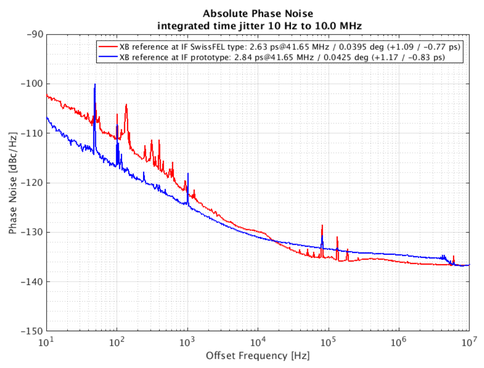

Figure 7: Abs. phase noise comparison of down converter

- Prototype X-band down converter (blue) shows less phase noise at offset frequencies below 20 kHz but slightly more at offsets above 20 kHz compared to previous dual frequency (X → S → IF) conversion X-band front end
- Final Phase Noise performance to be expected even better as prototype was made using partly unshielded evaluation boards and noisy biasing
- Performance comparison showed more significant improvements on amplitude noise (about 40% less) rather than phase noise

Conclusion / Outlook

Due to the high degree of system modularity, many components required for the overall RF front end functionality and system integration could be reused from previous S- and C-band front end developments, keeping the development effort at a minimum. They include the reference splitter, clock divider, adjustable IF amplifiers, digital interface and power supplies shown in Figure 3.

As development of the presented X-band front end is still ongoing, first system acceptance tests are to be expected in late 2019 while RF commissioning of SwissFEL Athos X-band deflector structure is scheduled for mid 2020. Furthermore exchange of currently used injector 4th harmonic X-band front end is foreseen to improve RF station noise performance.

Revision 1, DA82, 26.09.2019, presented at LLRF Workshop 2019 (LLRF2019, arXiv:1909.06754)